



# Electric Power Steering Device and Method for Controlling the Same

## Background of the Invention

### Field of the Invention

The present invention relates to an electric power steering device that gives a steering assisting force by using a motor and a method for controlling the electric power steering device.

### Description of the Related Art

In a related electric power steering device adapted to give a steering assisting force by using a motor, the steering assisting force is changed according to operating conditions, such as steering torque and a vehicle speed. However, in the case of employing such a related electric power steering device adapted to simply change the steering assisting force according to the operating conditions, when a steering speed is changed, a steering feeling is worsened under the influence of the inertia of a moving part of a steering system, which includes the motor. Thus, the following countermeasure is taken. That is, a rotation angular speed of the motor is obtained according to the inter-terminal voltage, electric current, resistance, counter-electromotive-force constant of the motor thereof. Then, an output of the motor is corrected according to a

rotation angular acceleration computed from the obtained  
rotation angular speed in such a manner as to compensate  
for the influence of the inertia of the moving part on  
steering. However, the obtained rotation angular  
5 acceleration of the motor lags behind an actual angular  
acceleration of the steering wheel, which is caused by  
actual steering. Consequently, the influence of the  
inertia cannot be compensated for with timing with which  
such influence should be compensated for. Thus, the  
10 steering feels heavy.

Thus, there has been proposed a related power  
steering device adapted to compensate for the influence of  
the inertia according to an angular acceleration of a  
steering wheel, which corresponds to a sum of a change  
15 acceleration of steering torque and a rotation angular  
acceleration of a motor, instead of a rotation angular  
acceleration of the motor (see Patent Document 1).

[Patent Document 1]

20 Japanese Patent No. 2,694,213.

However, the related device has encountered  
problems that when a steering direction is reversed at high  
speed, the related device cannot accurately compensate for  
25 the influence of the inertia with timing with which the  
device should compensate for the influence thereof, and

that a steering feeling is worsened.

### Summary of the Invention

Accordingly, an object of the invention is to  
5 provide an electric power steering device enabled to solve  
the aforementioned problems.

To achieve the foregoing object, according to the  
invention, there is provided an electric power steering  
device, which comprises a motor for generating a steering  
10 assisting force, means for obtaining steering torque, means  
for obtaining a rotation angular speed of the motor, means  
for obtaining a steering angular correspondence value,  
which corresponds to a sum of a value obtained by  
multiplying a change acceleration of the steering torque by  
15 a gain and a rotation angular acceleration of the motor,  
according to the obtained steering torque and the obtained  
rotation angular speed of said motor, means for regulating  
the gain, means for storing relation between a motor output  
correction value, which is preliminarily determined in such  
20 a way as to compensate for the influence of the inertia on  
steering, and the steering angular acceleration  
correspondence value, and means for controlling the motor  
in such a way as to correct a steering assisting force  
according to the motor output correction value obtained  
25 according to the obtained steering angular acceleration

correspondence value and the stored relation.

According to the invention, the influence of the inertia of the steering-assisting-force generating motor is compensated for according to a steering angular acceleration correspondence value, which corresponds to a sum of a value obtained by multiplying a change acceleration of the steering torque by a gain and a rotation angular acceleration of the motor. The gain can be adjusted. Thus, the ratio of the change acceleration of the steering torque to the rotation angular acceleration of the motor can be increased. Consequently, in the case that a steering angle is reversed at high speed, the motor output correction value, which corresponds to the steering angular acceleration correspondence value, can be increased. Thus, the influence of the inertia of the steering assisting force generating motor can be compensated for with accurate timing.

Preferably, a rate of increase in magnitude of the motor output correction value in a range, in which magnitude of the steering angular acceleration correspondence value is large, is set to be larger than a rate of increase in magnitude of the motor output correction value in a range, in which the magnitude of the steering angular acceleration correspondence value is small. Consequently, in the case that the magnitude of the steering angular acceleration correspondence value is

small, and that there is no necessity for compensating for the influence, the motor output correction value is prevented from becoming excessively large. Conversely, in the case that the magnitude of the steering angular acceleration correspondence value is large, and that there is high necessity for compensating for the influence, the motor output correction value is prevented from becoming insufficient. Proper inertia compensation is achieved.

#### Brief Description of the Drawings

FIG. 1 is an explanatory diagram illustrating the configuration of an electric power steering device that is an embodiment of the invention;

FIG. 2 is a control block diagram illustrating a motor, which is used for generating a steering assisting force, in the electric power steering device that is the embodiment of the invention;

FIG. 3 is a graph illustrating the relation among the steering torque, vehicle speed, and assist current value of the electric power steering device that is the embodiment of the invention; and

FIG. 4 is a graph illustrating the relation between the steering angular acceleration correspondence value and the compensation current value of each of the embodiment of the invention and a modification thereof.

In the drawings, the reference numeral 1 refers to

an electric power steering device; 2 to a steering wheel; 3 to a vehicle wheel; 10 to a motor; 20 to a control unit; 20d to a gain regulator; 22 to a torque sensor; 25 to an inter-terminal voltage sensor; and 26 to a motor current  
5 sensor.

### Detailed Description of the Preferred Embodiments

An electric power steering device shown in FIG. 1 has a mechanism for transmitting a rotation of a steering wheel (or operating member) 2, which is caused by steering,  
10 to vehicle wheels 3 so that a steering angle changes. In this embodiment, a rotation of the steering wheel 2 is transmitted to a pinion 5 through a steering shaft 4, so that a rack 6 meshing with the pinion 5 moves. The movement of the rack 6 is transmitted to the vehicle wheels  
15 3 through a tie-rod 7 and a knuckle arm 8. Thus, the steering angle is changed.

The device 1 is provided with a motor 10 for generating a steering assisting force, which acts upon a path for transmitting a rotation of the steering wheel 2 to  
20 the vehicle wheels 3. In this embodiment, a rotation of the motor 10 is transmitted to the steering shaft 4 through a reduction gear mechanism 11. Thus, a steering assisting force is given thereto.

The motor 10 is connected through a drive circuit  
25 21 to a control unit 20 constituted by a computer. A

torque sensor 22 for detecting steering torque  $T$  transmitted by the steering shaft 4, a steering angle sensor 23 for detecting a steering angle  $\theta_h$ , a vehicle speed sensor 24 for detecting a vehicle speed  $V$ , an inter-terminal voltage sensor 25 for detecting a voltage developed between the terminals of the motor 10, and a motor current sensor 26 for detecting a motor current are connected to the control unit 20. The control unit 20 obtains a rotation angular speed  $\omega$  of the motor 10 as a rotational speed of the motor 10 from the inter-terminal voltage and the motor current, which are respectively detected by the sensors 25 and 26, and from the resistance and the counter electromotive force constant of the motor 10, which are stored therein, by using a known operation expression.

The control unit 20 controls the motor 10 so that a steering assisting force changes according to operating conditions, and that the influence of the inertia of a moving part of a steering system, which includes the motor 10, on steering can be compensated for.

FIG. 2 is a control block diagram illustrating an operation of controlling the motor 10 by the control unit 20. An assist current value  $I_a$  is obtained according to the steering torque  $T$  and the vehicle speed  $V$ , which are obtained as the operating conditions, in an assist current computing portion 20a. The relation thereamong, in which

the magnitude of the assist current  $I_a$  increases with increase in that of the steering torque  $T$  and with decrease in the vehicle speed  $V$ , as illustrated in, for example, FIG. 3, is preliminarily determined and stored in the control unit 20. The assist current value  $I_a$  is obtained from the stored relation, the obtained steering torque  $T$ , and the obtained vehicle speed  $V$ .

A steering torque change rate  $dT/dt$ , which is a differential value of the obtained steering torque  $T$ , is obtained at a differentiator 20b. A value  $(1/K) \cdot (dT/dt)$  to be obtained by multiplying the steering torque change rate  $dT/dt$  by a constant  $1/K$  is obtained at a multiplier 20c. In this embodiment, torque to be transmitted by the steering shaft 4 is detected as the steering torque  $T$ . Thus, the constant  $K$  corresponds to the torsional stiffness of the steering shaft 4 of a torque detecting portion. In a case where the torque detecting portion is constituted by two members connected by a torsion bar, the constant  $K$  corresponds to the torsional stiffness of the torsion bar.

A value  $(K_g/K) \cdot (dT/dt)$  to be obtained by multiplying the value  $(1/K) \cdot (dT/dt)$  by a gain  $K_g$ , which is adjusted by a gain regulator 20d, is obtained at a multiplier 20e. The gain regulator 20d is connected to the control unit 20 and enabled to adjust the gain  $K_g$  by being operated by an operator.

A pinion angular speed  $(\omega/N)$  to be obtained by

multiplying the obtained rotation angular speed  $\omega$  of the motor 10 by a constant  $(1/N)$ . In this embodiment, an output of the motor 10 is transmitted to the steering shaft 4 through the reduction gear mechanism 11. Therefore, the constant  $N$  is a reduction ratio of the reduction gear mechanism 11.

A steering angular speed correspondence value  $u$ , which is a sum of the value  $(K_g/K) \cdot (dT/dt)$  and the pinion angular speed  $(\omega/N)$ , is obtained at an adder 20g.

10 A steering angular acceleration correspondence value  $du/dt$ , which is a differential value of the steering angular speed correspondence value  $u$ , is obtained at a differentiator 20h. Because  $du/dt = (K_g/K) \cdot d^2T/dt^2 + d\omega/dt \cdot (1/N)$ , the value  $du/dt$  is obtained according to the steering torque  $T$  and the rotation angular speed of the motor 10 as the steering angular acceleration correspondence value, which corresponds to a sum of a value obtained by multiplying the change acceleration of the steering torque  $T$  by the gain  $K_g$  and the rotation angular speed of the motor 10. The gain regulator 20d is provided as means for regulating the gain  $K_g$ .

The control unit 20 stores the relation between a motor output correction value, which is preliminarily determined in such a way as to compensate for the influence of the inertia on steering, and the steering angular acceleration correspondence value  $du/dt$ . In this

embodiment, the motor output correction value is a compensation current value  $I_c$ . The relation therebetween is determined so that a steering feeling can be prevented from being worsened under the influence of the inertia when a steering speed changes. The relation, according to which as the magnitude of the steering angular acceleration correspondence value  $du/dt$  increases, the magnitude of the compensation current value  $I_c$  linearly increases as indicated by solid lines in, for example, FIG. 4, is preliminarily determined and stored in the control unit 20.

This relation is stored therein in the form of, for instance, a lookup table or an operation expression. The compensation current value  $I_c$  is obtained at a computing portion 20i according to the stored relation and the obtained steering angular acceleration correspondence value  $du/dt$ .

A target drive current  $I^*$  of the motor 10, which is a sum of the obtained assist current value  $I_a$  and the compensation current value  $I_c$ , is obtained at an adder 20j.

The control unit 20 performs feedback control operations on the motor 10 through a drive circuit 1c so that the motor current  $I$  corresponds to the target drive current. Consequently, the motor 10 is controlled such that the steering assisting force is corrected according to the compensation current value  $I_c$ .

According to the aforementioned embodiment, the

influence of the inertia of the steering-assisting-force generating motor 10 is compensated for according to the value  $du/dt$  corresponding to a sum of the rotation angular acceleration of the motor 10 and the value obtained by multiplying the change acceleration of the steering torque  $T$  by the gain  $K_g$ . The gain  $K_g$  can be adjusted by the gain regulator 20d. Thus, the ratio of the change acceleration of the steering torque  $T$  to the rotation angular acceleration of the motor 10 of the sum can be increased.

Consequently, in a case where the steering direction is reversed at high speed, the compensation current value  $I_c$  corresponding to the steering angular acceleration  $du/dt$  can be increased, and the influence of the inertia can be compensated for with accurate timing.

In the aforementioned embodiment, the magnitude of the compensation current value  $I_c$  linearly increases with increase in the magnitude of the value  $du/dt$  corresponding to the steering angular acceleration, as indicated by a solid line in FIG. 4. Instead, as indicated by a double-dashed-chain line in FIG. 4, the rate of increase in the magnitude of the compensation current value  $I_c$  in a range, in which the value  $du/dt$  corresponding to the steering angular acceleration is large, may be set to be larger than that of the compensation current value  $I_c$  in a range, in which the magnitude of the value  $du/dt$  corresponding to the steering angular acceleration is small, as an alternative

modification. Thus, in the range in which the magnitude of the value  $du/dt$  corresponding to the steering angular acceleration is small, the magnitude of the compensation current value  $I_c$  is set to be smaller than that of the compensation current value  $I_c$  in the case of the  
5    aforementioned embodiment. Conversely, in the range in which the magnitude of the value  $du/dt$  corresponding to the steering angular acceleration is large, the magnitude of the compensation current value  $I_c$  is set to be larger than  
10   that of the compensation current value  $I_c$  in the case of the aforementioned embodiment. A range of the magnitude of the value  $du/dt$  corresponding to the steering angular acceleration from 0 to a shown in this figure is a dead zone in which the magnitude of the compensation current  
15   value  $I_c$  is set to be 0. Consequently, in the case that the magnitude of the value  $du/dt$  corresponding to the steering angular acceleration is small, and that the necessity for compensating for the inertia is low, the compensation current value can be prevented from becoming  
20   excessively high. Conversely, in the case that the magnitude of the steering angular acceleration correspondence value  $du/dt$  is large, and that the necessity for compensating for the inertia is high, the compensation current value can be prevented from becoming insufficient.  
25   Proper compensation for the inertia can be performed.

The invention is not limited to the aforementioned

embodiment and to the modification. For example, the rotation angular speed of the motor 10 may be directly detected by using an encoder. Alternatively, the rotation angular speed and the rotation angular acceleration of the motor may be obtained as the number of revolutions per unit of time and change in the number of revolutions per unit of time, respectively, instead of an angular speed and an angular acceleration. The mechanism for transmitting a rotation of the steering wheel to the vehicle wheels in such a way as to change the steering angle is not limited to that of the embodiment. This mechanism may be adapted to transmit a rotation of the steering wheel to the vehicle wheels through the steering shaft and a link mechanism. The mechanism for transmitting an output of the steering-assisting-force generating motor to a steering system is not limited to that of the embodiment. Another mechanism may be employed, as long as this mechanism can give a steering assisting force thereto. For instance, a steering assisting force may be given thereto by driving a ball nut to be screwed to a ball screw, which is integral with a rack, by using the output of the motor. Although the value  $(1/K) \cdot (dT/dt)$  is multiplied by the gain  $K_g$  in the aforementioned embodiment, the steering torque change rate  $dT/dt$  may be multiplied by the gain  $K_g$  as long as the steering angular acceleration correspondence value corresponds to a sum of a value obtained by multiplying a

change acceleration of a steering torque change  
acceleration by the gain and a rotation angular  
acceleration of the motor.

5 An electric power steering device according to the  
invention can compensate for the influence of the inertia  
of a motor, which is used for generating a steering  
assisting force, on steering with accurate timing and also  
can prevent a steering feeling from being worsened.

What is claimed is:

1. An electric power steering device comprising:  
a motor for generating a steering assisting force;  
means for obtaining steering torque;  
means for obtaining a rotation angular speed of  
5 said motor;  
means for obtaining a steering angular acceleration  
correspondence value, which corresponds to a sum of a value  
obtained by multiplying a change acceleration of the  
steering torque by a gain and a rotation angular  
10 acceleration of said motor, according to the obtained  
steering torque and the obtained rotation angular speed of  
said motor;  
means for regulating the gain;  
means for storing relation between a motor output  
15 correction value, which is preliminarily determined in such  
a way as to compensate for the influence of the inertia on  
steering, and the steering angular acceleration  
correspondence value; and  
means for controlling said motor in such a way as  
20 to correct a steering assisting force according to the  
motor output correction value obtained according to the  
obtained steering angular acceleration correspondence value  
and the stored relation.
2. The electric power steering device according to